INTERNATIONAL ENERGY AGENCY SOLAR HEATING AND COOLING PROGRAMME

TASK 18

Advanced Glazings and Associated Materials
for Solar and Building Applications

APPLICATIONS GUIDANCE AND TECHNOLOGY TRANSFER

FINAL PROJECT REPORT

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February 1997

1. INTRODUCTION

Advanced glazing materials offer a wide range of options for enhancing the optical and thermal performance of windows and the building envelope. Such materials are being researched because of the recognised potential for energy reduction, increased thermal insulation, solar gain control and improved thermal and visual comfort conditions in residential and commercial buildings. A major programme of international research collaboration in the field of advanced glazings within the International Energy Agency Solar Heating & Cooling (IEA SH&C) Programme was initiated in 1990. Task 18 “Advanced Glazing Materials” has participants from 15 OECD member countries and has been engaged in many diverse activities which have addressed all key issues relevant to the use of advanced glazing technology in buildings. The work encompasses basic materials research, window design and construction, optical and thermal performance definition, measurement and testing, building energy performance assessment using major thermal simulation tools, quantification of energy and environmental impacts arising from the use of advanced glazings, the identification of important applications and means to encourage the dissemination of high quality scientific and technical information. In the latter case, the Task aims to provide guidance for design engineers, architects, building engineers and industry professionals on the properties, use, performance and selection of advanced glazing materials

The objective of the Task is to develop the scientific, engineering and architectural basis which will support the appropriate use of advanced glazings in buildings and other solar applications with the aim of realising significant energy and environmental benefits.. Glazings under investigation included monolithic and granular aerogels, a wide range of transparent insulation materials, evacuated glazings or vacuum windows, low emittance coatings for both heat mirror and solar gain control applications, dynamic, or “smart”, glazings including electrochromic and thermochromic windows, and angle selective transmittance coatings for both energy and daylighting applications. The Task has also analysed the state of the art of frame and edge seal technology and produced design guidelines for advanced window components.

In addition to materials based R&D, the Task has been concerned with the measurement of all glazing properties necessary to determine performance and the development of associated recommended test procedures for such measurements. Properties measured include total energy transmittance: *the g-value*, (also known as the Solar Heat Gain Coefficient *(SHGC)*), the overall heat loss coefficient: *the U-value*, and spectral directional optical properties (transmittance, reflectance, emittance) for solar wavelengths. Data from these measurements have been used as input to window design tools and building energy analysis simulation tools to enable the total energy flows into and from the building to be assessed in heating and cooling dominated climates and to test control strategies necessary to integrate advanced windows into the building envelope and optimise building services.

The work of Task 18 has been very productive. Many useful outputs such as state of the art reviews and design guidelines have been produced in addition to more than 300 scientific and technical reports. The majority of the outputs have been produced as Working Documents and are indexed in full in the Task’s Information Plan. Other outputs have appeared in the refereed scientific literature of journals and conference proceedings. The work of the Task has undoubtedly contributed greatly to present undertanding in the field of advanced glazing. The challenge facing the Task at the end of its research phase is to identify appropriate means for maximising the impact of the Task for building professionals, i.e. how to dissseminate the results of the Task effectively ?

This end-point was identified at the planning stage of the Task and the project A5 identified as the vehicle through which information dissemination and technology transfer could be stimulated. This report sets out the current position in relation to progress achieved in the processing of information and knowledge gained from IEA SH&C Task 18 into forms suitable for use by different professionals in different countries. Much has been accomplished with the very limited resources available to the project but much more can still be achieved. As is inevitable with a Task of this nature a very large proportion of the total data has been generated or revised in the last 12 months of the Research Phase.

Further progress in the processing of the data into more convenient forms for widespread dissemination will occur during the final phase of the Task as the Technical reports are prepared.

2. PROJECT DEFINITION

2.1 Subtask A: Applications Assessment and Technology Transfer

Subtask A of Task 18 focussed on the application of advanced glazing systems in buildings and other solar energy systems. In order to facilitate technology transfer, it has been necessary to evaluate the energy and environmental benefits of the application of advanced glazings and their interaction with other aspects of building and systems design. This has involved the development of more credible methods of assessing the performance of buildings and systems containing advanced glazings.

The objectives of the work undertaken within Subtask A are:

- Investigation of the technical and economic potential of advanced glazing systems.
- Establishment of physical properties of advanced glazing materials and control strategies critical to performance.
- Evaluation of design tools and provision of applications guidance to aid the selection of advanced glazing systems.
- For defined building types and reference zones to study the climate dependence of performance.
- Comparison of performance obtained with different materials.
- Assessment of cost and benefits and the setting of target costs against other solutions.
- Determinination of the influence of degradation on thermal performance.

Without a proper understanding of the potential energy benefits, appropriate applications and necessary performance requirements of advanced glazing materials it is difficult both to demonstrate the effectiveness and potential advantages which will result from the use of such materials and to make educated choices in the selection of candidate glazing systems for either solar or building applications.. The results of Subtask A are of extreme importance to industry in making decisions related to product development, in the marketing of new products and in ensuring proper design selection, effective and appropriate application of the candidate materials.

To achieve the Subtask objectives, 5 projects (subsequently merged into 4 projects) were defined:

A1 Applications and Technology Transfer (Australia)

A2/ A3 Modelling and Control Strategies (USA)

A4 Environmental and energy impacts (Australia)

A5/B10 Applications guidance and technology summaries (UK)

Resource limitations presented the Task with serious problems. The planned start of the A5 Applications Guidance project, in the second half of the Research Phase, coincided with severe budget problems in many of the member countries who were originally planning to participate in the project. To deal with these difficulties a senior management decision was taken with approval by the SH&C Executive Committee to merge the leaderless A5 project with the Subtask B B10 project where much of the raw data arising from the work of the Task was being processed. This decision was taken some 2 years into the Task. Only 3 countries:UK, Finland and Australia, have made any serious contribution to A5/B10.

The first project, Applications, potentials and characteristics, aimed to determine appropriate applications for advanced glazing materials and the potential for their exploitation. As part of this project the parameters required to characterise materials and systems were reviewed to ensure that designers are provided with the necessary information to allow the specification of new products in this area. In order to identify appropriate applications, investigate climate dependence and predict potential energy and environmental benefits to be derived from the use of advanced glazing systems, Subtask A employed extensive computer simulation using state-of-the-art design tools. The results of this work are presented in the A2A3 Modelling and Cnotrol Strategies Final Project Report.

The results of the A1 and A2A3 Subtask A projects, together with data generated from the Subtask B projects formed the inputs to the A4 project which aimed o determine the energy and environmental impact of the applications of advanced glazing materials. This project provides information on the likely impact for different climatic regions and its outputs represent the achievement of the primary objective of the Subtask.

In order to ensure that the best possible use is made of the results of the Task, the A5 project was established to collate important information into applications guidance formats that can be incorporated into the dissemination programmes of each member state taking account of differences in climate and construction culture.

2.2 Project A5: Applications guidance

This project attempts to collate important results into applications guidance material that can be incorporated into the dissemination programmes of each participating country taking account of differences in climate and construction techniques.

The project objectives were:

- To develop guidance material for designers and their clients covering the application of advanced glazing materials to residential and non-residential buildings throughout a range of climates.

The main activities of the project were originally that the participants would:

(a) Publish technical summaries and performance characteristics of individual materials.
(b) Identify appropriate applications for specific materials across a range of building types.
(c) Identify practical constraints on the applications of advanced glazings.
(d) Publish advice on the availability and use of design tools.
(e) Publish advice on control strategies for switchable materials and building services.
(f) Identify energy and environmental implications of advanced glazing materials in buildings and other solar applications.

2.3 Project B10: Advanced glazings materials properties handbook and technology summaries

The project objectives were:

- To develop, maintain and promote the distribution of technical information on the properties of advanced glazings materials properties data base in forms of value to industry, architects and design engineers. Information from the whole Task will be processed to enable an integrated presentation of relevant properties for a wide range of advanced glazing materials.

The main activities of the project were identified to be:

- Identification and definition of relevant materials properties
- Literature review of materials properties and materials data bases relevant to advanced glazings
- Preparation of state-of-the-art reviews of advanced glazing materials
- Analysis of required formats for the presentation of technical information to interested parties

- Preparation of a technical handbook on advanced glazing materials and associated technology summary sheets (some of this information to be available in electronic media)

3. SUMMARY OF MAIN PROJECT ACTIVITIES

The main areas of activity within A5/B10 are listed below and discussed in detail in the following Sub-sections:

1. Preparation of a teaching and learning package for educationalists
2. Preparation of technology summaries
3. Generation of an advanced glazing materials database
4. Preparation of a glazing materials properties handbook
5. Development of an advanced glazings glossary
6. Formation of national industry clubs
7. Publication of national newsletters
8. Publication of a Task bibliography
9. Organisation of national and international conferences and industry workshops
10. Preparation of a Task 18 brochure, exhibition and display material
11. Preparation of a Task 18 video

3.1 Preparation of a teaching and learning package

With the aid of financial support from the national Engineering and Physical Sciences Research Council (EPSRC) the UK was able to develop a complete training course at the postgraduate equivalent level in the field of advanced glazing materials. The course entitled "Advanced Glazing Materials For Enhanced Energy Performance Of Building Envelopes" was written by Prof Michael Hutchins, Oxford Brookes University, and built upon work completed for the European Commission ALTENER programme in a project entitled "EASE" (Education for Architects in Solar Energy). The new course has been validated to run in Masters programmes throughout the UK in association with the stand-alone integrated graduate development scheme (IGDS). The module is equivalent to 100 hours of student effort and has a value of 10 M-level CATS points (equivalent to one-twelfth of a Masters degree programme).

The course objectives were defined to be:

- To understand patterns of energy use in residential and commercial buildings
- To define and calculate key glazing energy performance parameters
- To evaluate advanced glazing options for reduced energy consumption for heating, lighting and cooling of buildings
- To incorporate advanced glazing materials in modem window design
- To recognise the value of simulation tools in the design of energy efficient buildings

The course syllabus was defined to be:

Energy use in the built environment: review of energy use in residential and commercial buildings by fuel type and end use. Building codes. Influence of glazing on potential energy savings in buildings.

Solar and thermal radiation, optical properties, solar heat gain coefficient, U-value: centre, edge and total, calculation of heat transfer through glazing elements. Use of window desktop design tools: WINDOW, VISION, FRAME, FRAMEPLUS. Visual and thermal comfort.

High thermal performance glazing: low emittance coatings, monolithic and granular aerogels, transparent insulation materials, evacuated glazing. Daylighting glazing: angle selective transmittance coatings, holographic glazing. Dynamic glazing: switchable apertures, electrochromic, thermochromic and thermotropic windows.

Frame design and construction, thermal breaks, low thermal conductivity gas fills, insulating spacers, advanced frame materials, comparison of fibreglass, U-PVC, aluminium and wood frames. Condensation issues.

Building energy and environmental performance modelling, building energy analysis tools, window energy labelling and performance rating, ISO and CEN standards. Influence of glazing design and selection on annual energy provenance. Control strategies.

Embodied energy and life cycle analysis of glazing materials.

A full description of the module is attached as Appendix I.

3.2 Preparation of technology summaries

One-page summaries of all key areas of advanced glazing materials and technology have been written in a Microsoft Powerpoint format. The technology summaries provide an introduction and essential basic linformation on materials, frame and edge seal technology, glazing performance classification, optical and thermal properties etc. To date some 40 pages have been developed. The series remains under development. Examples of technology summary sheets are included in Appendix II.

3.3 Generation of an advanced glazing materials database

This work forms the most ambitious part of the A5B10 project. The databse has been constructed in Microsoft Access. The database contains the following information and tables:

- All samples tested in Task 18
- All measured properties of the samples distributed in Task 18
- All test laboratories
- A glazings experts address and specialisms list
- The glazings glossary
- Access to the technology summaries
- The Task 18 Information Plan and bibliography
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3.4 Preparation of a glazing materials properties handbook

The technology summary sheets and data from the Task 18 database are combined into paper form to produce a Handook of physical and thermal properties of advanced glazing materials, components and window systems. Analysis of all results arising from the Task 18 projects is currently in progress by the UK now that the Final Project Reports have been submitted. The Task 18 Experts' Meeting in Nagoya should result in agreement on the measured properties of glazings arising from the work of the participants.The Handbook will be published by Elsevier and the final draft will be completed following the Nagoya meeting.

3.5 Development of an advanced glazings glossary

Australia completed the initial work necessary to create a glossary of glazing terms within Project A1. The glossary is written in Microsoft Access and has been incorporated into the Task 18 database. Some updating and maintenance of the glossary should be planned into future activities to ensure its currency.

3.6 Formation of national industry clubs

To assist in the dissemination of research results and to create strong links between Task 18 and the glass and glazings industry, industry clubs were formed in Australia and the UK. These clubs have been very successful and have ensured awareness of the Task's work by a wider audience.

3.6.1 The UK Advanced Glazing Industry Club (AGIC)

The UK AGIC was established in 1993 to promote awareness within the UK Fenestration Industry (i.e. glass and glazings manufacturers, designers, architects and end-users of the technology) of current international best practice and new developments for improved thermal and optical performance of windows. It allows exchange of information between the IEA Task's researchers from OECD countries and the UK Industry. AGIC has played an important role in the dissemination of knowledge and identification of appropriate applications of advanced glazing products.

AGIC is a non profit-making organisation administered by the Advanced Glazing Technology Group at Oxford Brookes University. All funds generated from the annual membership fee are used to:

- provide technical and information services for AGIC members
- subsidise the dissemination activities for members (production of technical literature, organisation of seminars and workshops)
- ensure effective UK technical participation in Task 18
- promote the knowledge and use of advanced glazing products for the benefit of UK interests.

Raising industry awareness of advanced glazing technologies for reduced building energy performance and improved internal environment, and acting as a conduit for high quality technical information are the main motives for the existence of AGIC. AGIC concerns itself with technologies which are at research, near market or current international best practice stages.

Awareness raising is by articles/interviews in trade journals and building technology and architectural press, appearance at window industry trade exhibitions, technical papers at conferences for building technologists and designers.

Seminars have been held on developments in advanced glazing technologies for improved thermal and optical window performance.

Workshops for the industry have covered 2-D modelling of frame, spacer and edge of glazing heat flows, and glazing U-value, solar and light transmission and pane temperature calculation. AGIC are UK distributors of the FRAME software (5) developed by Enermodal engineering of Canada, and are users of the WINDOW and VISION software (6,7) from Lawrence Berkeley Laboratory and University of Waterloo respectively.

AGIC liaises with other UK organisations with access to people for whom advanced glazing technology is relevant, collaborating where it is of mutual benefit, for example:

- UK Branch of the International Solar Energy Society (UK ISES)
- Chartered Institute of Building Service Engineers (CIBSE)
- Centre for Window and Cladding Technology (CWCT)
- Building Environment Performance Assessment Club (BEPAC)
- National Physics Laboratory, Fenestration Performance Interest Group

The National Physics Laboratory Fenestration Performance Interest Group concerns itself with the measurement and calculation of glazing thermal properties, and international, European and British standards on procedures.

AGIC is also involved with the European Union who are providing funding for the development of continuing professional development educational materials for European architects on the application of current best practice high performance glazing systems in passive design. Several other proposals have been submitted for funding in the field of advanced glazing. The European Union are currently very supportive of this area of research, development, and dissemination, recognising its potential for reducing the reliance of European buildings on fossil fuels to maintain comfortable internal environments.

A full list of AGIC Members is attached as Appendix III.

3.6.2 The Australasian Advanced Windows Group (AAWG)

The Australasian Advanced Windows Group (AAWG) was formed in 1991 by the National Solar Architecture Research Unit (Solarch) at the University of New South Wales. Five Solarch staff are involved, full or part-time, in window energy research. Academic and consulting staff from Mechanical & Process Engineering and from the School of Optometry also provide optical characterisation and solar/thermal testing services. The AAWG is sponsored by Australia's Energy Research and Development Corporation (ERDC), which manages government funding for energy R&D on a matching investment basis with industry. ERDC also represents Australia on the Executive Committee of the International Energy Agency's Solar Heating & Cooling Programme. The University of New South Wales was appointed by ERDC to lead Subtask A of the International Energy Agency's Task 18 project on advanced glazing materials. Subtask A is important to the ultimate success of Task 18 because it emphasises technology transfer and user impacts of emerging advanced windows, including environmental costs and benefits. It is to underpin industry participation in Task 18 that the AAWG was formed.

The AAWG is an industry-research club with over 100 member organisations across Australia and New Zealand. Similar in concept to the UK's Advanced Glazing Industry Club, it provides liaison and technical backup for industry and other Australian companies and universities, whether or not they are involved directly in Task 18. Members receive a twice-yearly newsletter, A Window To The Future, which contains a blend of industry news, technical features and snapshots of R&D world-wide, particularly Task 18 and the NFRC. For example, members may order Task 18 technical reports and papers through the AAWG. Task 18 has quickly adopted the use of the Internet to enable its participants to communicate easily by e-mail, as they are scattered across 15 countries. The Task maintains a file (FTP) site in Canberra, Australia to facilitate exchange of Task documents. More recently, a general IEA 'home page' has been set up in New Zealand on the World Wide Web (URL http://www-iea.vuw.ac.nz:90:/). This facility provides text and colour graphics either on-screen or as printout and is accessible to any computer with an Internet connection. Although so far it has been used primarily by researchers, the rapid growth in the use of 'the Web' by business means that industry has a powerful new tool for advertising, providing applications guidance materials, and keeping in touch with the research community as well as its peers.

The Australasian Advanced Windows Group holds twice-yearly seminar days and training workshops for WINDOW, VISION and FRAME. To reinforce the knowledge base of the AAWG, since 1992 the University of New South Wales conducted, with industry, a Professional Development Course in Window Design and Performance Technology. This certificate course has been targeted at management, senior technical and sales/marketing personnel from leading glass and window companies in Australia and New Zealand. The most recent event took the form of a three-day live-in course which covered structural, safety, legal, quality assurance and weathertightness issues in addition to energy performance.

Although the early focus of the AAWG was very much on energy and comfort issues, its scope has broadened with the formation of the Australasian Window Council. The overall mission statement of the Australasian Window Council is "to develop, implement and manage an industry-wide quality assurance system for the window products industry in Australia and New Zealand". As in most countries, the impact of new window technology in Australia and New Zealand has emphasised quality accreditation, environmental impact, standards initiatives and consumer demands for greater comfort.

In establishing the AWC, it was recognised that in the United States and the United Kingdom the introduction of new technology and accompanying legislation has had a considerable impact on the existing marketplace, some of which has caused problems, e.g. insulating glass failures and wood preservative failures (UK) and U-value standards (California). Meanwhile, Australia has had a very fragmented approach to maintaining high standards for consumers to enjoy. State-by-state parochialism, political differences and a widely-scattered population have all exacerbated this trend. Another problem is the tendency of industry to become fragmented into rival lobby organisations, such as vinyl-versus-wood-versus-aluminium windows. In legitimately defending market shares, this competition (with its conflicting claims) also confuses the consumer and retards progress towards new standards. Independent credible benchmarks are needed to assess claims about window energy performance - hence the development of the unified Window Energy Rating Scheme for Australasia, along the lines of the NFRC's, but not the same. This is but the first of a number a quality assurance-related projects that the AWC will co-ordinate. It is an example of the strategy of integrating exemplary energy performance into the quality assurance programmes to complement non-energy issues such as wind and rain penetration, glazing safety standards, materials and finishes. Real progress has already been made by Australia's Residential Window Association in the adoption of a national window weathertightness-labelling scheme (similar to New Zealand's successful system) identifying the performance and national accreditation of their products.

3.7 Publication of national newsletters

In addition to the Newsletters published by AGIC and AAWG referred to above, Task 18 stimulated the USA, through the windows and Daylighting Group of the Lawrence Berkeley Laboratory, university of california, to produce a newsletter entitled Fenestration News. These regular publications in the host nations provide an excellent means of focussing national attention.

3.8 Publication of a Task bibliography

The Task failed in its original aim to produce a comprehensive bibliogrpahy of seminal papers. The work was started in A2A3 but was put aside because of poor response from member countries outside the USA. A draft bibliogrpahy working document exists.

3.9 Organisation of national and international conferences and industry workshops

Task 18 has been highly successful in organising national and international conferences to disseminate research results and form new links with industry.. The Task organised the highly successful Window Innovations '95 conference in association with the Canadaian Government department CANMET and has held industry workshops in Australia and Japan. Many national conferences have used Task 18 as a catalyst for their programmes and papers presented.

3.10 Preparation of a Task 18 brochure, exhibition and display material

Task 18 produced and distributed some 4,000 brochure describing the work of the Task. In addition a poster exhibition was prepared in Microsoft Power Point format and 13 A!-sized full colour poster boards were prepared in the form of a travelling exhibition. The display was used to form the International energy Agency stand at the Glastec 96 exhibition held in Dusseldorf, Germany. Some 49,000 visitors attended the Glastec 96 exhibition and many new and professional contacts were made.

3.11 Preparation of a Task 18 video

Australia has prepared a video alerting professional audiences to the work of Task 18 which should have a value in boosting interest in the final outputs of the Task.

4. CONCLUSIONS

The technology of fenestration systems has advanced greatly in the last ten years. Many exciting technologies have emerged which have the promise, if applied wisely, to realise significant economic, comfort and environmental benefits for buildings and their owners and users. By now the process of co-ordinating basic and application research is quite mature, with structured projects being undertaken by many OECD members (e.g. Canada, US, Japan, Europe, Australia). These projects are carried out at a local level to help realise local goals, such as those of the National Fenestration Rating Council, or the Joule II Programme of the European Union, but are also co-ordinated internationally through projects like the International Energy Agency Task 18 Advanced Glazing Materials. Such projects are largely supported by government research funding to address identified priority areas in pure and applied science and the environment, for example. Sponsorship from other stakeholders such as manufacturers and energy utilities is becoming increasingly important also.

However, many challenges must be overcome if high-performance windows are to achieve a significant share in the marketplace by the year 2000. The problems include high initial cost, lack of knowledge, and great conservatism in industry and among the diverse market - architects, building engineers, window specifiers, building owners and occupants.

The world-wide recession has slowed new building construction and made building owners and home builders and buyers very cost-sensitive. The retrofit market is vast and largely untapped in many countries. Incentive programmes are normally required to encourage the adoption of better products. A partnership of prescriptive regulation and financial "carrot and stick" measures must be developed in each region. Another strategy is to integrate exemplary energy performance into the quality assurance programmes which cover non-energy issues such as wind and rain penetration, glazing safety standards, materials and finishes.

Education programmes on energy conservation and renewable energy, in addition to specialised training courses on advanced window technology fro industry, help raise awareness and competence in the marketplace. One powerful approach is for manufactures to market advanced windows on the basis that they can equal or outperform walls or roofs. For example, superwindows or TIMs having U-values below $1W/m^2K$, return a net energy gain in any climate. In hot climates "cool daylight" glazings or electrochromic systems, coupled with continuous dimming may outperform single glazings and external shades on the basis of total building energy use and capital costs. Aswell as cost benefits, the amenity value of increased usable space and improved comfort levels (and associated increase in occupant satisfaction, resulting in , in commercial buildings, increased productivity) should be considered.

The activities undertaken within this project will assist educators, industry, the consumer and the environment to gain the maximum benefit from emerging advanced window technologies. The project is by no means complete. The most serious factors which have impeded completion of the project in its originally conceived form are (a) lack of resources and commitment from the members countries, and (b) the volume of information generated by the Task, much of which has been in the final phase of the work. There is clearly a serious need to press on with the job of processing this information and finding new resources to aid its dissemination and enhance the impact of the Task on a wider audience. Much more work will be done by the UK during 1997 but there are no committed resources from other countries. The UK will make available the maximum possible information to the participants wh will then have the task of reorganising the material to meet their national needs. Some elements of the work will be taken up in the proposed new IEA SH&C Task which should commence at the end of the current year.

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APPENDIX I

ADVANCED GLAZING MATERIALS FOR ENHANCED ENERGY PERFORMANCE OF BUILDING ENVELOPES

A Module developed at the Masters Level for Professional Training and Development

OXFORD
BROOKES
UNIVERSITY

School of Engineering

An application to EPSRC for funding for the development of an individual Module at Masters degree level

ADVANCED GLAZING MATERIALS FOR ENHANCED ENERGY PERFORMANCE OF BUILDING ENVELOPES

June 1995

1. THE MODULE

(a) ***Proposed Title:*** Advanced Glazing Materials for Enhanced Energy Performance of Building Envelopes

(b) ***Objectives***

It is intended that the module will enable the student to:

- Understand patterns of energy use in residential and commercial buildings
- Define and calculate key glazing energy performance parameters
- Evaluate advanced glazing options for reduced energy consumption for heating, lighting and cooling of buildings
- Incorporate advanced glazing materials in modem window design
- Recognise the value of simulation tools in the design of energy efficient buildings

(c) ***Content***

(i) *Outline*

A specialised study of advanced glazing materials in the design and construction of energy efficient windows and their influence on the energy performance of buildings.

(ii) *Proposed Syllabus*

Energy use in the built environment: review of energy use in residential and commercial buildings by fuel type and end use. Building codes. Influence of glazing on potential energy savings in buildings.

Solar and thermal radiation, optical properties, solar heat gain coefficient, U-value: centre, edge and total, calculation of heat transfer through glazing elements. Use of window desktop design tools: WINDOW, VISION, FRAME, FRAMEPLUS. Visual and thermal comfort.

High thermal performance glazing: low emittance coatings, monolithic and granular aerogels, transparent insulation materials, evacuated glazing. Daylighting glazing: angle selective transmittance coatings, holographic glazing. Dynamic glazing: switchable apertures, electrochromic**,** thermochromic and thermotropic windows.

Frame design and construction, thermal breaks, low thermal conductivity gas fills, insulating spacers, advanced frame materials, comparison of fibreglass, U-PVC, aluminium and wood frames. Condensation issues.

Building energy and environmental performance modelling, building energy analysis tools, window energy labelling and performance rating, ISO and CEN standards. Influence of glazing design and selection on annual energy provenance. Control strategies.

Embodied energy and life cycle analysis of glazing materials.

(d) *Delivery*

(i) *Study Mode*

Students will be required to attend for two weeks of teaching. The course will be delivered in two
one-week blocks. Each teaching block will be followed by a period of student-centred study.

(ii) *Teaching and Learning Methods*

The first week of study will employ a series of lectures which address theory and application. Laboratory sessions will address the properties of advanced glazings, window design and performance assessment through the use of desktop simulation tools. Students will identify topics for individual research and case studies for analysis. During the first week there will be 12 one-hour lectures, 2 three-hour practical sessions and two one-hour tutorial sessions.

During the second week of formal contact, each student will present a seminar for supported by a written position paper on the selected topic. Case studies will be evaluated by multi-disciplinary small groups. Further lectures on specialised topics will be presented by leading professionals in the field drawn from industry and leading practices. Following the second week of contact, students will complete a paper on an identified topic.

Specialist teaching materials are currently being developed for building professionals are architects by Oxford Brookes University within the EU ALTENER programme. A module pack comprising slides, overhead transparencies, software and self-directed study aids will be developed to aid student centred learning.

(e) *Foundation/Amplification*

The University can offer pre-module work packages to remedy deficiencies in energy sources and building
physics.

A reading list will be compiled which can be used in support of the module and for subsequent reference
purposes. Further modules will be developed to meet CPD and postgraduate demand.

(f) *Assessment*

(i) *Methods*

100% of marks will be awarded for coursework consisting of

30% Research paper
30% Seminar presentation and position paper
20% Case study exercises
20% Design and calculation exercises

(ii) *Pass / Fail Criteria*

In order to obtain a pass in the module the student must obtain an aggregate mark of 40 % for the whole assessment. A distinction grade may be awarded to a student who obtains an aggregate mark of not less than 70 % for the module assessment.

(g) *CATS Rating*

The module will be equivalent to 100 hours of student effort and will have a value of 10 M-level CATS points. Approval will be sought for the module to be recognised for CPD activity by relevant professional institutions, e.g. Institute of Energy, Chartered Institute of Building

Service Engineers, Royal Institution of British Architects. NVQ validation potential will be investigated.

(h) *Prerequisites*

The module will be aimed at a multidisciplinary market. Normal entry requirements will be a first degree in physics, engineering or architecture. Others with relevant professional experience will be considered individually.

(i) ***Cost***

The provisional registration fee will be £1000 although the University reserves the right to revise this sum
in the light of final costings.

(j) ***Course Links***

The University already offers a Postgraduate Diploma and MSc in Energy Efficient Buildings. It is
intended that this module will become an acceptable component of this course.

2. THE CONTRACTORS

(a) ***Academic Institution***

The lead academic institution is Oxford Brookes University and the module will be offered by the School of Engineering. The University will collaborate closely with the Building Research Establishment and Pilkington Ltd who currently support research activities in advanced glazing within the School of Engineering.

Contact name: Professor Michael G Hutchins
Head, Electronics, Physics and Electrical Engineering School of Engineering
Oxford Brookes University
Headington
Oxford OX3 OBP

Tel: 01865 483604
Fax: 01865 483929
email: mhutchins@brookes.ac.uk

(b) ***Relevant Experience***

Oxford Brookes University is a nationally and internationally centre of expertise in the area of advanced glazing technology for energy efficient buildings. The University acts as Operating Agent (Lead Institution) for the International Energy Agency Solar Heating and Cooling Programme Task 18 Advanced Glazing Materials. This project receives financial support from the Building Research Establishment (BRE), Garston, and the Energy Technology Support Unit (ETSU), Harwell. Task 18 is the world's largest programme of collaborative international research and development in advanced glazing technology with participation from 15 OECD countries. To facilitate information dissemination and best practice, Oxford Brookes University, on behalf of ETSU, founded the UK Advanced Glazing Industry Club (AGIC) with sponsorship from Pilkington, National Power, Anglian Windows, English Architectural Glazing and the University of Ulster. AGIC is a focal point for advanced glazing applications and currently has more than 30 members representing the glass and glazings industry, window manufacturers, building service engineers, architectural practices, consultants and universities. In addition the School of Engineering is engaged in a large number of research projects fielded by the European Union JOULE and ALTENER programmes, the Ministry of Defence and Pilkington in the field of spectrally selective and spectrally responsive transparent thin films, switchable glazing systems and solar control coatings.

Additional useful experience has been gained in designing and teaching the MSc in Energy Efficient Buildings and the EU ALTENER EASE project which specifically aims to develop teaching materials to be used by architects on CPD courses.

3. QUALITY ASSURANCE AND MANAGEMENT

(a) Procedures

AN new course proposals are subject to the University validation procedures as set out in the Quality
Assurance Handbook (May 1994).

The module will be subject to Annual Review and major Quinquennial Review as determined by the
University Quality Assurance procedure.

The following criteria will typically be used to monitor the performance of the module:

(a) number of companies involved and level of commitment to the module
(b) ratio of applications for entry to places taken up
(c) number of student registrations compared to annual targets
(d) ratio of enrolments to successful completions
(e) course evaluation by students and industrial partners
(f) assessment performance
(g) annual and quinquennial review outcomes as judged by quality assurance procedures
(h) financial performance as measured by income and expenditure in relation to budget forecasts
(i) level of sales
0) accreditation for Continued Professional Development purposes by outside institutions.

(b) *Updating*

The module will be subject to review and critical appraisal at the end of each academic year in line with the University's current procedures and practice. Advice and opinions will be sought from participating students and supporting industry and companies to ensure the relevance and currency of the course material.

(c) *Management*

The development of the module will be managed by Professor M Hutchins of the School of Engineering,
Oxford Brookes University. The University will collaborate closely with the Building Research Establishment, the Energy Technology Support Unit and Pilkington.

4. THE MARKET

More than 50% of UK delivered energy is consumed in buildings. Government-funded research estimates that the potential energy and environmental benefits of introducing advanced glazing into UK buildings are very significant, reducing primary energy demand by more than *5* % and reduction of annual greenhouse gas emissions by 10% by 2025. Education programmes on energy conservation and specialised training courses on advanced window technology, help raise awareness and competence in the marketplace. Manufacturers can market advanced windows on the basis that they can equal or outperform walls or roofs and return a net annual energy gain. Raising industry awareness of glazing technologies for reduced building energy performance and improved internal environment together with acting as a conduit for high quality technical information and applications guidance have been the prime objectives of Oxford Brookes Advanced Glazing Industry Club and the primary outputs of the IEA Task 18 Advanced Glazing research programme. Oxford Brookes has become a nationally and internationally recognised centre of expertise and has developed effective working links with all areas of relevant industry and commercial practice from materials development through to building design and performance assessment. As such Oxford Brookes is ideally placed to maximise the benefits accruing from its research standing and its links with the UK glass and glazings industry. The course will be marketed against a background of nationally recognised expertise and as such will prove popular and relevant to key areas of the building industry.

5. INDUSTRIAL INVOLVEMENT

Oxford Brookes University will maximise its industrial links established through AGIC and jointly funded research together with its links to Government agencies supporting the International Energy Agency Programme. In particular participation in planning and marketing will be co-ordinated with Pilkington, the Building Research Establishment and AGIC members. Specialist lectures will be arranged and delivered by working professionals in the field. Visits to industry will be planned and made where appropriate.

APPENDIX II

ADVANCED GLAZING TECHNOLOGY SUMMARIES

Selected Examples of Technology Summary Sheets
prepared by the UK and Germany

Low-emittance Coatings

Low-emittance coatings form the basis of the state-of-the-art of multiple-glazed insulating glass units. Such coatings, which may combine high solar and visible transmittance with low thermal emittance, are manufactured by all major glass and glazing companies worldwide. They represent a mature technology, are widely available and are being increasingly used in double, and even triple, glazed units to achieve very high thermal resistance whilst preserving good levels of solar and light transmittance. The visual quality of these coatings is very good with little, or no, observable haze.

Thin-film low-emittance coatings may be deposited onto float glass by sputtering (physical vapour deposition) or by spray pyrolysis (chemical vapour deposition). Sputtering is commonly used to deposit multilayer thin films on glass which has been previously cut and loaded onto the coating line. Pyrolytic coatings are normally formed on the float line by deposition onto the surface of the hot glass after it has left the tin bath.

Pyrolytic coating is normally used to produce heavily doped wide bandgap semiconductors such as fluorine-doped tin oxide (SnO_2:F). These coatings are exceptionally durable and have good handling properties. K-GLASS, manufactured by Pilkington, is an excellent example. The heavy doping of the semiconductor gives it metal-like properties and is responsible for the low thermal emittance. Typical values of thermal emittance, ε, are $0.1 \le \varepsilon \le 0.2$. The solar transmittance is typically $\tau_s = 0.65$, and the visible transmittance, τ_v, is high, typically $\tau_v = 0.81$. Coatings which combine high values of τ_s and τ_v with low values of ε are commonly termed "heat mirrors". Film thickness is normally around 1 μm, thick enough to avoid iridescence effects. The spectral transmittance and reflectance[1] of Pilkington K-GLASS is shown in Fig. 1.

The optical properties quoted above are typical for all heavily doped semiconductor heat mirrors. The doping levels needed to produce the low thermal emittance in semiconducting pyrolytic coatings cannot be made high enough to enable these coatings to selectively transmit the visible component of the incident solar radiation whilst reflecting the near infrared solar wavelengths. Such spectral selectivity is possible with thin noble metal films and forms the basis of multilayer solar control coatings. High visible transmittance can be maintained whilst the total solar gain is reduced. Sputtered multilayer thin films also enable the manufacture of surfaces with lower thermal emittance than is achieved with pyrolytic coatings.

Traditionally pyrolytic coatings have been termed "hard coats" and sputtered multilayers "soft coats". Whilst this distinction is a little too simplistic, pyrolytically deposited heat mirrors are very resistant to handling and the environment, whereas sputtered multilayers damage more easily and require protection from the environment, usually achieved by incorporation in a sealed and dehumidified multiple glazing unit (which may be double or triple).

The possibilities of tailoring the optical properties of coated glass to meet the needs of use in different climates are much greater with the sputtered multilayer films. The use of very thin films of the noble metals, usually silver, means that coatings can be designed to pass a high proportion of visible radiation whilst reflecting much of the near infrared component of the incident solar radiation. Optimised multilayer coatings can exhibit $\tau_v = 0.66$, $\tau_s = 0.32$ and $\varepsilon = 0.03$. Such coatings are highly attractive for restricting solar gain, maintaining high daylight levels and reducing thermal losses in buildings and are commonly termed "cold mirrors".

The thin noble metal film is antireflected using high refractive index thin film oxides such as SnO_2, TiO_2 or Bi_2O_3 to improve transmittance. The multilayer thin film stack acts as a versatile bandpass filter which can be tuned by altering the thicknesses of the individual layers. This allows the coating to be designed to meet the needs of either warm climates (high visible transmittance, low solar transmittance) or cold climates (high visible transmittance, high solar transmittance) and emittance values are lower than those which can easily be produced with pyrolytic coatings. The spectral transmittance and reflectance of two IPASOL product, tuned Bi_2O_3-Ag- Bi_2O_3 multilayers produced by Interpane, Germany, are shown in Fig 2a and 2b. Here the solar transmittance is varied $0.34 \le \tau_s \le$

0.38, and the visible transmittance, τ_v, is either $\tau_v = 0.52$ or $\tau_v = 0.66$. Thermal emittance values below $\varepsilon = 0.06$ are achieved.

Sputtered low-e coatings may also be applied to plastic sheets, such as those manufactured by Southwall, USA, which can be tensioned and suspended within glazing units.

Thermal conductivity, and hence the U-value of double and triple glazed units can be reduced by replacing the air in a sealed unit with an inert noble gas. Argon is the most common choice for a substitute gas fill but further reductions in U-value, with additional cost, can be achieved with krypton and xenon. Optimum gap spacing in the sealed unit is gas dependent. The dependence of the convective heat transfer coefficient, h_{conv}, on gas type and gap spacing[2] is shown in Fig. 3.

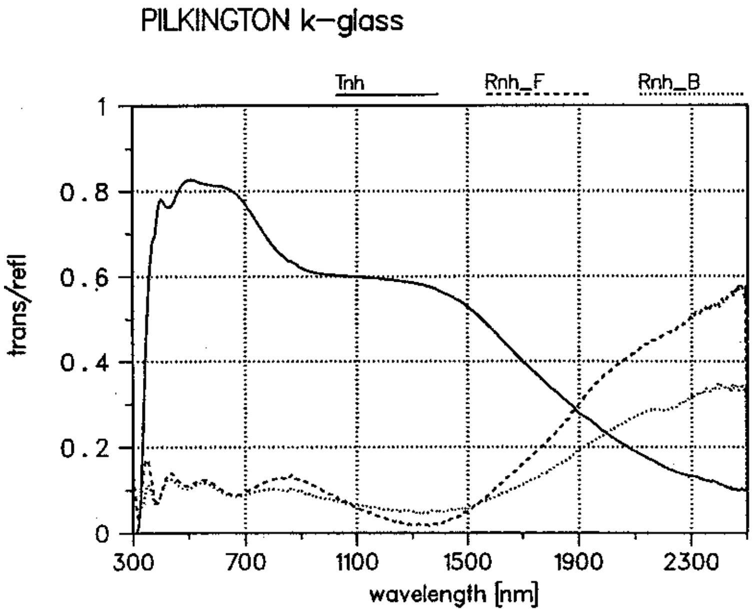

Figure 1. Spectral transmittance and reflectance of Pilkington K-GLASS (both front and rear surface spectral reflectance shown).

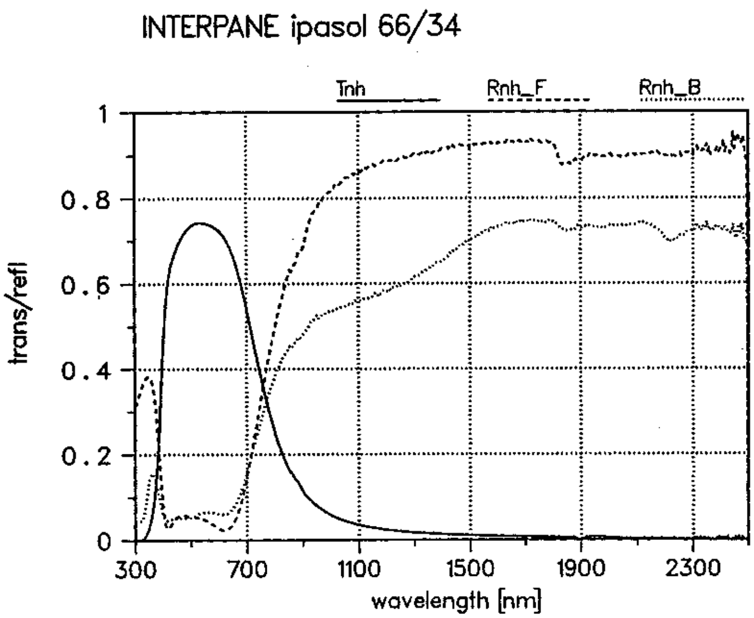

Figure 2a. Spectral transmittance and reflectance of Interpane IPASOL 66/34 multilayer solar control low-e coated glass (both front and rear surface spectral reflectance shown).

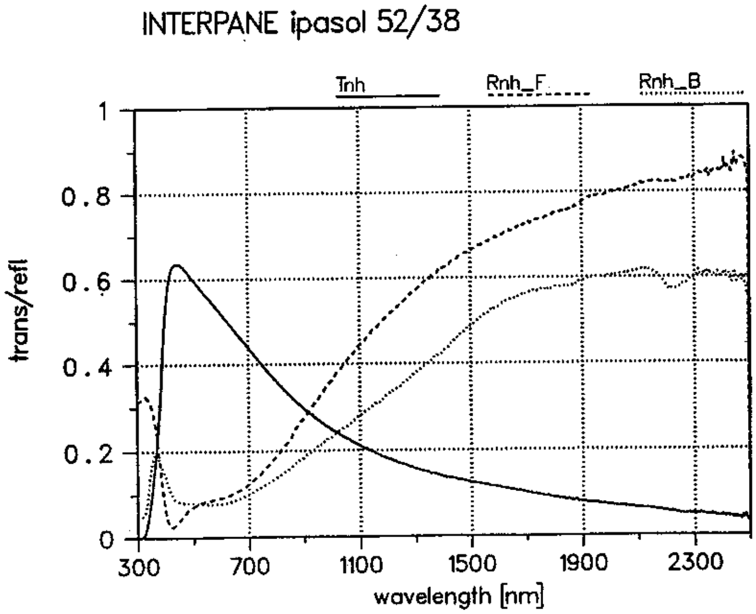

Figure 2b. Spectral transmittance and reflectance of Interpane IPASOL 52/38 multilayer solar control low-e coated glass (both front and rear surface spectral reflectance shown).

Monolithic and granular aerogels

Aerogel is a microporous silicate “foam”, with pore sizes of about 10 nm, which may be produced in granular or monolithic forms. Monolithic tiles may be formed from alcogels by supercritical drying with densities in the range
100-150 kg m^{-3}. Such tiles may be sandwiched between two glass sheets and partially evacuated. The objective is to minimise thermal losses whilst maintaining high levels of solar gain. Target performance levels for the monolithic aerogel window are total energy transmittance, g = 0.75, and total heat loss coefficient, U = 0.75 W m^{-2} K^{-1}.

Monolithic aerogel materials exhibit high solar and visible transmittance, $\tau_s \geq 0.87$, $\tau_v \geq 0.84$. However pronounced light scattering occurs at short wavelengths due to the small pore size of the aerogel structure and the material appears blue in transmission and yellow in reflection[3]. This phenomenon is unacceptable for applications such as normal view windows. Representative total and diffuse spectral transmittance properties of monolithic aerogel are shown in Fig. 4. Recent changes in the production process have produced materials with lower short wavelength scattering.

Monolithic aerogel cracks easily, is difficult to handle, and has poor resistance to water. To date difficulties exist in producing monolithic tiles of dimensions greater than 60 x 60 x 2 cm^3. Such windows are not available commercially.

Monolithic glazing units formed by sandwiching the aerogel tile between two glass sheets and partially evacuating the enclosure reducing the U-value substantially. An additional problem in glazing construction is to form an effective edge seal of high integrity. Danish patents for the edge sealing of aerogel windows have been filed.

Granular aerogel windows have been produced commercially by Interpane, Germany, with aerogel granules manufactured by BASF. The granules fill the central space of a partially evacuated double glazed unit and the windows are translucent. Performance is affected by granule size and overall window thickness. Total energy transmittance $0.3 \leq g \leq 0.5$ and $0.4 \leq U_c \leq 1.0$ W m^{-2} K^{-1} have been achieved. Heat conductivity is higher than that of the monolithic aerogel because of the voids. Granular windows have potential in daylighting applications.

Transparent Insulation Materials

Transparent insulation materials (TIMs) are geometric arrays of tubes, slats or honeycombs. They may be polymeric or glass. Strong directional optical properties and scattering prevent their use as view windows. TIMs have applications in mass wall solar collectors, skylights, light shelves etc. A major disadvantage is the need to use thick (50 -100 mm) materials to achieve U-values in the range 1.0 - 1.5 W m^{-2} K^{-1}. Sealed glazing units cannot be used and special spacer and edge seal technology is required. Possible TIM geometries[4] are shown in Fig. 5.

Heat transfer is dominated by radiative transport and is thickness dependent. Small cell geometry reduces convection and radiative heat exchange. Near-normal solar and visible transmittance are very high (close to 1). Pronounced angular dependence means that the total transmittance is seasonally dependent as the Sun's altitude varies. The transmittance can vary by some 20% from winter (highest) to summer (lowest). Polycarbonate honeycombs, e.g. AREL, and capillary structures, e.g. OKALUX, are commercially available. Directional diffuse hemispherical solar and light transmittance[5] for the AREL and OKALUX glazings are shown in Figs. 6 and 7 respectively as a function of the thickness of the TIM.

Glass capillary structures have been developed by Schott, Germany, which reduce scattering, improve uniformity of the structure and improve temperature resistance. Detailed data on the performance of this TIM is not available.

Evacuated glazing

Elimination of gaseous conduction and convection by the use of a vacuum between two glass sheets could lead to a window with high thermal insulation and good optical properties. Radiative heat transfer is minimised by the use of a transparent low emittance coating on the internal surfaces of one or both of the two glass sheets. Many practical difficulties have to be overcome in order to produce an evacuated glazing unit. These include the method of ensuring a leak-free edge seal, the maintenance of a high vacuum between the glass sheets for the working life of the unit, and the withstanding of stresses set up by atmospheric forces.

Large area (1.0 x 1.0 m^2) evacuated glazings are being produced by the University of Sydney, Australia, and represent the state-of-the-art in this technology[7]. The two glass sheets are separated by an array of small (~ 0.3 mm) glass pillars and a fused solder glass edge seal is employed. A schematic representation of this window is shown in Fig. 7.

Pillar conductance and radiative transfer contribute to the heat losses. Only the pyrolytically deposited low emittance coatings can withstand the high temperatures necessary for formation of the edge seal. The higher thermal emittance of these coatings results in U-values of about 1.0 $Wm^{-2}K^{-1}$. A low temperature edge seal technique which would permit the sputtered low emittance coatings to be used, or a reduction in emittance of present pyrolytic coatings to around 0.05, would result in increased thermal resistance and U-values of about 0.5 $Wm^{-2}K^{-1}$ could theoretically be achieved

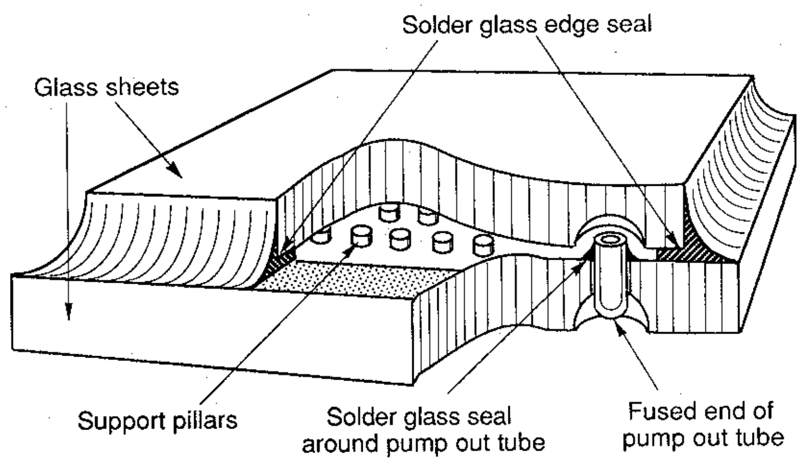

Figure 7. Schematic diagram of vacuum glazing as currently made at the University of Sydney

Thermal performance of insulating glazing materials

It is difficult to present single values for each of the key performance parameters of different advanced glazing materials. In addition key parameters vary for different glazing types.

For example the glass and glazing industry specifies the performance of low-e coatings through the use of near-normal solar and visible optical properties[6]. Hemispherical values of solar, visible and total energy transmittance are lower but are not normally quoted in manufacturers' data. Furthermore, it is not useful for building envelope design to specify the properties of an individual low-e coating, but rather the performance parameters of the glazed unit within which the coated glass is a component part. Spectral optical properties data are required at the window design level and are used as inputs to desktop design tools such as WINDOW 4.1 and VISION[8]. Performance of double and triple glazed low-e based insulating glass units depends also on choice and thickness of glass and on the gas fill. Window U-values will depend upon the details of edge seal, frame design and ratio of frame to glazed areas. Such values are not quoted here.

Table 1. lists representative values of the visible light transmittance, near-normal total energy transmittance and centre-of-glass U-value for different insulating glazing units employing low-e coatings for cold climate (heat mirror) and warm climate (cold mirror, solar control) applications. Where a range of values is given this is dependent on the emittance of the low-e coating.

In the case of aerogel and transparent insulation materials, whose main applications are not as view windows, it is usual to quote hemispherical performance parameters. As such direct comparisons with the properties of insulating glazing units employing low-e coatings should be made with care as the numbers are not necessarily measures of the same physical property. Aerogels and TIMs are normally enclosed within a glazed environment and the glazings may, or may not, be coated with low emittance films. In addition the solar gain and thermal loss terms of these materials will depend strongly on the thickness of material used. The level of evacuation of the glazed enclosure, if applicable (aerogels), will also influence the thermal losses. With these factors in mind Table 2. lists representative thermal performance parameters of aerogel and transparent insulation materials.

Glazing	**Gas Fill**	τ_v	g_n	**U ($Wm^{-2}K^{-1}$)**
Single	-	0.90	0.86	6.4
Double glazed unit (DGU)	Air	0.81	0.76	2.9
DGU, low-e	Air	0.74-0.78	0.62-0.71	1.8 - 2.2
DGU, low-e pyrolytic heat mirror	Argon	0.75	0.72	1.9
DGU, low-e sputtered noble metal heat mirror	Argon	0.75	0.58	1.1
DGU, low-e sputtered noble metal heat mirror	Xenon	0.76	0.58	0.9
DGU, low-e sputtered solar control	Argon	0.66	0.34	1.2
Triple glazed unit, 2 low-e	Argon	0.62-0.67	0.49-0.58	0.8-1.1
Triple glazed unit, 2 low-e	Krypton	0.63	0.55	0.7

Table 1. Thermal performance of insulating glazing units using low emittance coatings (τ_v = near-normal visible transmittance; g_n = near-normal total energy transmittance).

Glazing	τ_s	τ_v	τ_{sd}	τ_{vd}	g_h	**U ($Wm^{-2}K^{-1}$)**
Monolithic Aerogel	0.87-0.90	0.84-0.87	0.05-0.20	0.07-0.22	0.73	0.46
Granular Aerogel					0.50	0.84
Polycarbonate capillary TIM (glazed, t = 40 mm)	0.66	0.78				1.36-1.71
Polycarbonate capillary TIM (glazed, t = 80 mm)	0.65	0.77				0.84-1.36
Polycarbonate honeycomb TIM (glazed, t = 50 mm)	0.85	0.84				1.36
Polycarbonate honeycomb TIM (glazed, t = 100 mm)	0.85	0.84				0.87

Table 2. Thermal performance of aerogel and transparent insulation glazings
Polycarbonate capillary: Okalux 6/40/6 and 6/80/6; Polycarbonate honeycomb: Arel 3/50/3 and 3/100/3, low-iron glass

Representative thermal performance parameters of prototype evacuated glazings are listed in Table 3. Note the lowest U-value quoted has not yet been realised in practice because the pyrolytic low-e coatings required in this prototype do not have $\varepsilon = 0.1$.

Evacuated glazing	τ_v	g_n	**U ($Wm^{-2}K^{-1}$)**
One low-e, $\varepsilon = 0.2$	0.75	0.72	1.2
Two low-e, $\varepsilon = 0.1$-0.2	0.68	0.65	0.85 -1.0

Table 3. Thermal performance of evacuated glazing

Insulating glazing costs

The figures given in Table 4. are indicative costs only. Prices[7] are quoted in US $ equivalent.

Glazing	**US $/m²**
DGU, air, no low-e	18 ± 2
DGU, argon, low-e, heat mirror	26 ± 3
DGU, argon, low-e, solar control	40
Plastic capillary TIM (100 mm)	68
Evacuated glazing, 2 low-e	40 ± 7
Evacuated glazing, 1 low-e	32 ± 6

Table 4. Indicative costs of advanced glazing materials

APPENDIX III

UK ADVANCED GLAZING INDUSTRY CLUB

List of Members

UK ADVANCED GLAZING INDUSTRY CLUB

MEMBERS

1. SPONSORS

Mr A Wilkinson, Anglian Windows Ltd, PO Box 65, Norwich NR6 6EJ

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Andy Sherratt, Pilkington Technology Ltd, Hall Lane, Lathom, Ormskirk, Lancs. L40 5UF

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